METHANE RECOVERY FROM ANIMAL MANURES: A CURRENT OPPORTUNITIES CASEBOOK VOLUME I

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VOLUME I TABLE OF CONTENTS

VOLUME I TABLE OF CONTENTS CONTINUED **PAGE**

LIST OF TABLES

LIST OF TABLES CONTINUED **PAGE**

LIST OF FIGURES

LIST OF FIGURES CONTINUED

PAGE

LIST OF FIGURES CONTINUED

PAGE

1.0 EXECUTIVE SUMMARY

The growth and concentration of the livestock industry creates disposal problems for the large quantities of manures generated at feedlots, dairies, swine and poultry farms, animal holding areas, and pasturelands. The principal pollutants from livestock wastes are methane emissions resulting from manure decomposition, ammonia, excess nutrients, and pathogens. The major pollution problems associated with these wastes are surface and ground water contamination, and surface air pollution due to odors, dust, volatile organic acids, and ammonia. Also, there is concern about the contribution of methane emissions to climate change via the greenhouse effect associated with global warming, and its potential to deplete stratospheric ozone. Consequently, manure management systems that enable pollution prevention as well as energy production are becoming increasingly attractive.

This Casebook examines some of the current opportunities that exist for the recovery of methane gas from the anaerobic digestion of animal manures in the United States. The Casebook is presented in two volumes. Volume I is narrative, and Volume II provides the results of the computer-based economic evaluations used in one section of the narrative.

Volume I introduces the types of anaerobic digesters currently operating on livestock production facilities, and some of the end-use applications for methane gas manufactured as a result of the digestion process. Following this introduction is a series of *pro forma* economic evaluations of three types of anaerobic digesters found on farms in the United States. The selected technologies include covered lagoon, plug flow, and complete mix anaerobic digesters. The evaluations are based on engineering studies of digesters that generate electricity as the end-use application on dairy and swine farms with differing herd sizes. Regression models, which can be used to estimate digester cost and internal rate of return as a function of herd size, are developed from the evaluations. To provide a reality base, a number of operating and non-operating anaerobic digestion systems are presented as case studies. Information on actual project and maintenance histories, and on the operator's "lessons learned", is provided.

The economic evaluations and case studies indicate that anaerobic digestion of livestock manures is a commercially available technology with potential for providing a cost-effective alternative fuel which can readily be used by a number of livestock production operations. Of the conversion systems evaluated, covered lagoon digesters appear to have great economic merit for a large number of swine and dairy farms in the Southeast and West which incorporate hydraulic flushing for manure collection and conventional anaerobic lagoons for waste treatment. Plug flow digestion is economically sensitive to co-product utilization and other off-sets from current manure management practices, but it is less expensive and technically easier to operate and maintain than a comparable complete mix digester. Complete mix digesters have higher capital costs and operating and maintenance requirements than covered lagoon and plug flow digesters. This will generally limit complete mix digester applications to larger farms or centralized facilities having waste streams with total solid concentrations too low for plug flow digestion and to locations where the climate is too cold to economically justify digestion in a covered lagoon.

It must be remembered that the anaerobic digestion process is biologically-based, and therefore must be evaluated and implemented on a site-specific basis. As a result, few meaningful generalizations can be made. Key factors for successful project implementation include: an adequate match of digester type to the farm's manure management program, competent design and installation which simplifies digester operation and maintenance, maximization of co-product utilization to enhance economic performance, and, overall, an accommodating farm management and its willingness to incorporate the uncertainties of a new technology.

The list of reasons explaining why some anaerobic digestion projects fail must be headed by bad design or installation. When selecting the "best" qualified contractor to design or install an anaerobic digester system, an investor should rarely consider a firm without a significant amount of practical experience in the field. The second reason why digesters fail is poor equipment and materials selection. Although buying the best and most expensive equipment and materials available cannot guarantee project success, amortizing the cost of quality components over the life-cycle of the project must be preferred to a failure resulting from the use of inferior products. The third reason is related to farm management. Even the best designed and installed digester made of quality components will fail in the hands of the "wrong" farm.

The conversion of agricultural wastes, animal manures in particular, into an alternative energy resource has been the focus of intensive research for well over two decades. Much has been learned about how manure can be utilized as an energy and nutrient source. However, the American farmer has not been motivated to adopt these new practices. More cost-effective and easily-managed manure management techniques are needed to encourage farmers to use their animals' waste for conversion into energy and nutrients. Not only will farmers benefit monetarily, the use of anaerobic digestion will also help mitigate animal manure's contribution to air, surface, and ground water pollution. Additionally, there are indirect benefits for rural economic development from the implicit multiplier effect resulting from direct jobs that can be created by providing, installing and maintaining the digester system equipment.

Promising future waste-to-profit activities may enhance the economic performance of the overall farm manure management system. New end-use applications that can provide added value to co-products and maximize nutrient utilization include fuel cells for the generation of electricity and process heat, greenhouses, aquaculture, and algae production. Extension of the anaerobic digestion process with methane recovery has considerable potential for other industries with a waste stream characterization similar to livestock manures. Among others, example industries include milk, livestock, food, fiber, and pharmaceutical processing. Some of these industries already operate anaerobic digestion facilities and recover methane for energy.

As a portion of the methane emission reduction component of the *Climate Change Action Plan*[1] announced in 1993, the US Environmental Protection Agency (USEPA) and the US Departments of Energy (USDOE) and Agriculture (USDA) will expand a voluntary pollution prevention program with the livestock industry. By signing the Memorandum of Understanding (MOU) in the voluntary *AgStar* program, a livestock producer agrees to explore profitable methane reduction activities. Under the MOU, producers survey farm facilities to identify profitable opportunities to capture and use methane. *AgStar* producers will install systems for the recovery and use of methane only where it is profitable to do so. Market penetration estimates indicate that between four and five thousand dairy and swine farms could economically justify the implementation of anaerobic digestion from energy production offsets alone. *AgStar* will address two significant barriers which limit on-farm methane recovery: (1) lack of familiarity with and understanding of available technologies; and (2) lack of effective financing mechanisms to implement those technologies.

A key *AgStar* element is educational outreach that will explain the anaerobic digestion approach to the agricultural community and others. Workshops, comprehensive workbooks, and "field-day" tours will be available. *AgStar* will also support practical demonstration projects on working farms to help increase the rate of market penetration of this technology by informing livestock producers about the merits of anaerobic digesters. USEPA and USDOE are scheduled to conduct additional research and development activities. Their objective is to expand the universe of economically justifiable opportunities across the livestock production sector by developing more cost-effective technologies for a wider range of facility sizes. Areas of activity may include: digestion processes and systems, gas recovery, handling and utilization systems, and effluent utilization systems.

Because *AgStar* spans three major livestock groups (swine, dairy, and poultry), and cost-effective options exist for each of these commodity groups, the potential for large program participation is apparent. USEPA, USDOE, and USDA are scheduled to make an extensive effort to identify key groups, organizations, and other institutions which can promote the program to producers at the county, state, regional and national level. USEPA, USDOE, and the USDA also are set to make an extensive effort to identify federal, state, local, and private lending institutions to develop financing mechanisms to assist producers in implementing cost-effective technologies.

[1] Clinton and Gore. (1993) *Climate Change Action Plan*. Executive Office of the President, Washington, DC.

2.0 INTRODUCTION TO ANAEROBIC DIGESTION

Biogas is produced by the anaerobic ("without air") digestion of various types of plant and animal organic materials by bacteria in an airtight reactor commonly called a digester. Although some effort has focused on the anaerobic digestion of poultry manures, the manures from dairy and swine operations tend to be more suitable for farm-based energy conversion. This is because dairy and swine manure management systems are often liquid- or slurry-based, which simplifies manure movement.

The biogas produced by the anaerobic digestion process is quite similar to "natural" gas as it is extracted from the wellhead. Depending on the digestion process, the methane content of biogas generally ranges between 55 and 70 percent (500 to 650 Btu per standard cubic foot). The remaining composition is primarily carbon dioxide, with trace quantities (parts per million) of corrosive hydrogen sulfide.

Conventional anaerobic digesters, as will be explained in greater detail, are commonly designed to operate in either the mesophilic temperature range (68 degrees F to 113 degrees F) or thermophilic temperature range (113 degrees F to 150 degrees F). There are usually two reasons why these temperature ranges are preferred. First, a higher loading rate of organic materials can be processed, and because shorter retention times are associated with higher temperatures, increased outputs for a given digester capacity result. Second, a higher temperature increases the destruction of pathogens present in raw manure. Anaerobic digestion can also occur in the psychrophilic temperature range (less than 68 degrees F), but this range has not been as extensively evaluated by the research community.

The biogas produced by anaerobic digestion is suitable for use in engine/generators to produce electricity, boilers to produce hot water or steam used for sanitary washing, or in gas-fired absorption chillers used for refrigeration. When the biogas is used to produce electricity, there remains the potential for harvesting thermal energy from the engine's exhaust and cooling systems. Some digesters successfully compress the biogas to operate light-duty farm equipment as well.

2.1 US FARM-BASED ANAEROBIC DIGESTION PRACTICES

During the energy crises of the mid- and late-1970's, substantial attention was devoted to the development of alternative energy resources. In the agricultural sector of the nation's economy, these alternatives included ethanol from carbohydrate feedstocks, diesel fuel substitutes from oilseed crops, and methane-rich biogas from animal manures and food processing wastes.

The search for alternative energy resources led to investigation of small- and medium-scale anaerobic digesters developed in India and China to determine whether these technologies were directly transferable to farms in the United States (US). Unfortunately, while these technologies are useful in providing fuel for cooking and lighting in developing economies, the majority of the 6-8 million digesters installed in Asia are much too small to be useful to most American farmers. For example, the typical small-scale digester daily produces about the same amount of energy as contained in one gallon of propane[1].

The greater energy requirements of the larger-sized American livestock operations led to the design and installation of several digesters using model municipal sewage treatment plant technology. These demonstration projects represented a transfer of state-of-the-art sewage treatment plant technology and were the first complete mix digesters installed for agricultural application. Although complete mix digesters can operate in the thermophilic temperature range, the demonstration projects at facilities such as the Washington State Dairy Farm in Monroe[2] operated only in the mesophilic temperature range. At the Monroe project, the digester was sized for the manure volume produced by a milking herd of 180 to 200 Holstein cows. Although these early complete mix digesters generally produced biogas at the target design rate, they suffered from high capital costs and from significant operation and maintenance requirements. In practical application on the farm, the issues of solids settling, scum formation, and grit removal often presented major problems.

Today's complete mix digesters typically handle manure with a low solids content and generally can handle substantial manure volumes. The digester reactor is a large, vertical, poured concrete or steel circular container. The manure is collected in a mixing pit by either a gravity-flow or pump system. The total solids percentage can be diluted and the manure can be pre-heated before it is introduced to the digester reactor. The manure is deliberately mixed within the digester reactor. The mixing process creates a homogeneous substrate which prevents the formation of a surface crust and keeps solids in suspension. Mixing and heating often improve digester efficiency with an average retention time as low as 10 to 20 days.

A fixed cover is placed over the complete mix digester reactor to maintain anaerobic conditions and to trap the methane that is produced. The methane is removed from the digester, processed, and transported to the site of end use application. The most common application for the methane produced by the digestion process is electricity generation using a modified internal combustion engine. Both the digester reactor and the mixing pit are heated with waste heat from the engine cooling system. As already mentioned, complete mix digesters operate at either the mesophilic or thermophilic temperatures ranges. Lower temperatures reduce the rate of methane production, and

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1 Volunteers in Technical Assistance (1979) *Design and Construction of a Three-Meter Anaerobic Digester*. VITA, Mt Ranier, MD.

2 Coppinger, Baylon and Lenart (1980) Economics and operational experience of a full-scale anaerobic dairy manure digester. IN *Biogas and Alcohol Fuels Production*, ed. J. Goldstein, The JG Press, Emmaus, PA.

consequently, a digester operated in the mesophilic range requires a longer average manure retention time and a larger tank. Complete mix digester volumes range considerably from about 3500 cubic feet to 14,000 cubic feet. This represents daily capacities of about 25,000 gallons to 100,000 gallons of manure per digester. Larger volumes are usually handled in multiple digester systems.

As a simple extension of Asian anaerobic digestion technology, by the late-1970's researchers at Cornell University[3] were able to reduce the capital costs and the operational complexities associated with the early complete mix digesters. These "plug flow" digesters were adopted with some success in the cooler climate of the Northeast, where farms primarily use scraping systems for manure removal. The 1979 project at the Mason Dixon Dairy Farm in Gettysburg, Pennsylvania was the first plug flow digester operated on a commercial farm. At the Mason Dixon project, the plug flow digester was originally sized for a manure volume produced by a milking herd of 350 to 400 Holstein cows. The Mason Dixon Farm has since expanded to a total herd of over 3,500 cows and has built additional facilities to accommodate the increased manure volume.

The basic plug flow digester design is a long trough, often built below ground level, with an air tight expandable cover. The manure is collected daily and added at one end of the trough. Each day a new "plug" of manure is added, slowly pushing the other manure down the trough. The size of the plug flow system is determined by the size of the daily "plug". As the manure progresses through the trough, it decomposes and produces methane that is trapped in the expandable cover. In order to protect the flexible cover and to maintain optimal temperatures, some plug flow digesters are enclosed in simple greenhouses or insulated with a fiberglass blanket. The retention time, the total time that manure spends inside the digester as it flows from one end to the other, is from 20 to 30 days depending on the digester temperature. An often vital component of a plug flow digester is the mixing pit. A mixing pit allows the percent total solids of the manure to be adjusted by dilution with water. Many systems use a mixing pit with a capacity roughly equal to one day's manure output to store manure before being added to the digester.

Plug flow digesters operate at either the mesophilic or thermophilic temperature ranges. The amount of methane produced depends on the quantity of manure and the average retention time in the trough. Lower temperatures will slow the rate of digestion, which will require a longer retention time, and consequently, a larger, more expensive trough. Higher temperatures will increase the rate of digestion, which allows a shorter retention time and a smaller, less expensive trough. Energy for heating the digester is available in the waste heat from the exhaust and cooling system of an internal combustion engine/generator powered by the biogas produced in the digester.

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[3] Jewell *et al.* (1979) Low cost methane generation on small farms. Paper presented at *Third Annual Symposium on Biomass Energy Systems*, Golden, CO.

The complete mix and plug flow digestion technologies are not suited for use on farms that use hydraulic flushing systems for manure removal and anaerobic lagoons for waste treatment. An anaerobic lagoon is an increasingly popular method used to store and treat manure. A properly designed and operated lagoon system, where the manure retention time exceeds sixty days, will produce significant quantities of methane. In the early-1980's, the concept of using a floating cover that collects biogas as it escapes from the surface of an anaerobic lagoon emerged. The first floating cover that recovered biogas from an anaerobic lagoon operating in the psychrophilic range was at the Royal Farm operation in Tulare, California[4]. The Royal Farm's digester used the manure from a 1,600-sow farrow-to-finish farm. A workbook describing another covered lagoon digester constructed at the Randleigh Dairy in North Carolina is provided in the Appendix. The workbook provides information on system components and the performance that can be expected from this type of digester.

The methane produced in an anaerobic lagoon is captured by placing a floating, impermeable cover over the lagoon. The cover is constructed of an industrial fabric (e.g., hypalon) that rests on solid floats laid on the surface of the lagoon. The cover can be placed over the entire lagoon or the portion of the lagoon that produces the most methane. Once the cover is installed, the methane produced under the covered area of the lagoon is trapped. The biogas is harvested using a collection manifold, such as a long perforated pipe, that is placed under the cover along the sealed edge of the lagoon. Methane is removed by the pull of a slight vacuum on the collection manifold (e.g., by connecting a suction blower to the end of the pipe) that draws the collected biogas out from under the cover and on to the end-use application.

The cover is held in position with ropes and anchored by a concrete footing along the edge of the lagoon. Where the cover attaches to the edge of the lagoon, an air-tight seal is constructed by placing a sheet of the cover material over the lagoon bank and down several feet into the lagoon, and clamping the cover (with the footing) onto the sealed bank. Seals are formed on the remaining edges by using a weighted curtain of material that hangs vertically from the edge of the floating cover into the lagoon.

The covered lagoon digester has several merits. First, it has good potential for widespread adoption in the United States, especially in the southeastern and southwestern regions, because many facilities use hydraulic flushing for manure collection and anaerobic lagoons for waste treatment. Second, the construction and management of this type of reactor is simple and straightforward when compared to complete mix and plug flow digesters. Third, the capital costs for this type of digester are considerably less than that required for the two types of conventional digesters.

[4] Chandler, Hermes and Smith (1983) A low-cost 75-kW covered lagoon biogas system. Paper presented at *Energy from Biomass and Wastes VII*, Lake Buena Vista, FL.

However, although covering an anaerobic lagoon and harvesting the biogas is a simplified technology, the approach raises at least two significant concerns. A key issue is that digestion rate is dependent on temperature; therefore, biogas production varies seasonally if the lagoon is not externally heated. This means that methane production is greatest in the warm, summer months and lowest during the cooler, winter months. At the Randleigh Dairy, daily biogas production during the summer averaged 35 percent greater than daily production during the winter. This may make end-use applications more problematic than it is with conventional digesters which have less significant seasonal variations in methane production. Moreover, any anaerobic lagoon (covered or not) is impractical in areas with a high water table because of the potential for ground water contamination. Lagoons built into highly permeable soils should be adequately lined to prevent ground water contamination.

A number of other types of anaerobic digesters have been proposed for farm use, including variations of anaerobic lagoons generally referenced as Advanced Integrated Pond Systems (AIPS)[5]. AIPS use a submerged canopy covering a facultative pond, where the organic wastes are completely converted into methane, nitrogen, carbon dioxide, and stable residues. The submerged canopy is potentially more cost-effective than covered lagoons because it is not exposed to weather and other elements. One intriguing aspect of AIPS is that following the digestion process, effluent is discharged into pools and is used as a growth culture for algae. The algae are up to 50 percent protein and can be used for many purposes. Current operations produce algae for animal feed and soil amendment. Other algae that could be grown include *Spirulina*, a super-nutrient that contains Beta-Carotene, lipid-rich algae that could be converted into a liquid diesel fuel substitute, and algae that could be used as natural colorants or dyes.

Other types of anaerobic digesters discussed for farm-application, but not yet commercially used on livestock operations in the US, include packed reactors, upflow sludge blankets, and sequencing batch reactors. Although these technologies offer potential for reducing the number of days required for the anaerobic process, they comparatively suffer from higher capital and operating costs, as well as a greater level of process and operational complexity than the three types now in commercial operation.

2.2 ANAEROBIC DIGESTION AND THE ENVIRONMENT

The growth and concentration of the livestock industry creates disposal problems for the large quantities of manures generated at feedlots, dairies, swine and poultry

[5] Oswald (1993) Ponds in the twenty-first century. Paper presented at *2nd International Association of Water Quality Conference on Waste Stabilization Ponds and the Reuse of Pond Effluents*, Oakland, CA.

farms, animal holding areas, and pasturelands. The principal pollutants from livestock wastes are methane emissions resulting from manure decomposition, ammonia, excess nutrients, and pathogens. The major pollution problems associated with these wastes are surface and ground water contamination, and surface air pollution due to odors, dust, volatile organic acids, and ammonia. Also, there is concern about the contribution of methane emissions to climate change via the greenhouse effect associated with global warming, and its potential to deplete stratospheric ozone. Consequently, manure management systems that enable pollution prevention as well as energy production are becoming increasingly attractive.

The federal government's efforts to control agricultural non-point sources of pollution has been slow to develop because control of point sources was viewed as being more cost-effective. Solutions to non-point problems mainly involved land-use planning and practices that are largely the responsibility of state and local governments. Most federal efforts to control agricultural non-point sources have emphasized a voluntary, non-regulatory approach based on the implementation of best management practices (BMPs) instead of command-and-control regulations. In developing BMPs, states often take economic, institutional, and technical factors into consideration.

Section 319 of the federal Clean Water Act created a program to control non-point sources of pollution and to protect ground water. Each state is required to submit an assessment of state waters not expected to meet water quality standards because of non-point source pollution. Each state is also required to develop a management program for controlling non-point source pollution. Most agricultural activities have been classified as non-point sources of water pollution. Livestock non-point sources of water pollution include range and pastureland, feeding and watering sites, confinement facilities and manure disposal areas. These wastes are widely dispersed and are more difficult to regulate than effluents from point sources such as sewers and pipes. Including point sources, agriculture is now alleged to be the leading source of water pollution in the country[6]. Many livestock producers believe that these figures are not accurate and are biased upwards due to sampling of only those waters known to have water-quality problems.

Increased methane concentrations in the atmosphere may have important impacts on global climate change, ground-based ozone, and stratospheric ozone. Methane is considered to be one of the most potent greenhouse gases. Each molecule of methane is estimated to have 22 times the heat trapping impact of a carbon dioxide molecule. The US Environmental Protection Agency (USEPA) estimates that the

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6 Weinberg (1991) EPA programs addressing animal waste management. 1991. In *Proceedings of the National Workshop on Livestock, Poultry and Aquaculture Waste Management*. American Society of Agricultural Engineers.

atmospheric concentration of methane is increasing at one percent per year and has more than doubled over the past two centuries[7].

US livestock manures are estimated to emit about 3 million metric tons of methane annually and account for approximately 10 percent of the total US methane emissions[8]. Swine and dairy production facilities account for 80 percent of these emissions. About 1 million metric tons, or 33 percent of these emissions, have the potential to be profitably reduced at many swine and dairy farms. Based on life-cycle cost analysis of proven methane recovery technologies such as covered lagoons, plug flow and complete mix reactors, a necessary waste management liability can become a profit-making asset. Among waste handling systems, the potential for energy production from liquid-based systems is greater than for solid-based systems, because liquid-based systems encourage anaerobic digestion. Liquid-based systems (anaerobic lagoons and liquid/slurry storage) account for 40 percent of US emissions, while solid-based systems (pasture/range, daily spread, solid storage, and drylots) account for the remaining 60 percent.

The federal government does not now have any formal rules or regulations aimed at reducing methane emissions from livestock manures. However, as part of the strategy for stabilizing global methane concentrations, the USEPA and other organizations are identifying and evaluating various options for reducing a variety of methane emissions. As will be discussed in Section 5, these organizations are currently in the process of developing voluntary initiatives to capture methane produced by livestock manures and convert it into an on-farm alternative energy resource.

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[7] Safley *et al.* (1992) *Global Methane Emissions From Livestock and Poultry Manure.* U.S. Environmental Protection Agency (EPA/400/1-91/048)

[8] U.S. Environmental Protection Agency (1993) Methane Emissions from Livestock Manure (Chapter Six) IN *Opportunities to Reduce Anthropogenic Methane Emissions in the United States: Report to Congress.* (EPA-430-R-93-012)

3.0 ECONOMIC EVALUATION OF ANAEROBIC DIGESTION

Given that there are a number of anaerobic digestion technologies available, it is desirable to evaluate them using objective economic criteria. Such economic criteria allows technology options to be ranked in terms of their relative cost-effectiveness so that a rational decision may be made between the competing choices.

This section presents a series of *pro forma* economic evaluations of three types of anaerobic digesters commonly found on dairy and swine farms. The technologies include covered lagoon, plug flow, and complete mix anaerobic digesters. These digesters were assumed to generate electricity as the end-use application of the biogas manufactured from the anaerobic process. These evaluations were employed, in part, to develop regression models which can be used to estimate digester cost and internal rate of return as a function of herd size. The evaluations also were used to illustrate the importance of maximizing co-product utilization and other offsets which can result from technology adoption. This Section provides a narrative discussion of these evaluations, and Volume II provides the computer print-outs.

3.1 DISCUSSION OF METHODS AND DATA

The first objective of this Section is to develop regression models that can be used to estimate digester cost and internal rate of return as a function of herd size. The types of digesters analyzed are those that are commonly found operating on dairy and swine farms today: covered lagoon, plug flow, and complete mix. Each technology was evaluated using three different herd sizes. Dairy farms were further differentiated by the use of two manure collection scenarios. The first is apron only, which results in relatively low manure collection of about 15 percent of the total farm manure. The second collection scenario is apron and parlor, which results in a high manure collection of about 55 percent of total farm manure. All swine manures were assumed to be collected. Although plug flow digesters are operating on swine farms, they were analyzed only on dairy farms under the high manure collection scenario. Thus, a total of 21 digesters were evaluated under seven specific scenarios. All of the basic system data used in this objective were drawn from the US Environmental Protection Agency[1] (USEPA) and are listed in Table 3.1.1. Some of the USEPA assumptions were modified during the *pro forma* modeling, as will be noted later.

A second objective of this section is to illustrate the importance of maximizing co-product utilization and other offsets made available by adopting anaerobic technology. Once again, the types of digesters analyzed were covered lagoon, plug flow, and

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[1]. U.S. Environmental Protection Agency (1993) Methane Emissions from Livestock Manure (Chapter Six) IN *Opportunities to Reduce Anthropogenic Methane Emissions in the United States: Report to Congress*. EPA-430-R-93-012.

TABLE 3.1.1 ANAEROBIC DIGESTION OF LIVESTOCK MANURES DATATABLE

MACRO VARIABLES FOR CashFlow MODEL

enter	1.5	% Real Growth Rate in O&M Expenses
enter	0.0	% Real Growth Rate in Energy Expenses
enter	8.5	% Real Discount Rate
enter	40.0	% Combined Tax Rate
enter	0	Depreciation of System Capital Cost Method enter 1 for SL or 0 for 150% DB
enter	7-Year 150	Tag Line for Depreciation Line-Item in CashFlow

Dairy Farms w/ Electricity Generation & Low Manure Collected (15%)

SYSTEM	NAME	HEAD	SITING	TKEY	sum	aO&M	aSAV	pLIFE
DCLEL250	Dairy Covere	250	15,000	34,600	49,600	600	4,400	15
DCLEL500	Dairy Covere	500	15,000	47,800	62,800	1,200	8,700	15
DCLEL1000	Dairy Covere	1000	15,000	73,700	88,700	2,300	17,400	15
DCMEL250	Dairy Compl	250	15,000	61,500	76,500	400	2,300	20
DCMEL500	Dairy Compl	500	17,900	75,000	92,900	800	4,700	20
DCMEL1000	Dairy Compl	1000	23,200	98,900	122,100	1,700	9,300	20

Dairy Farms w/ Electricity Generation & High Manure Collected (55%)

SYSTEM	NAME	HEAD	SITING	TKEY	sum	aO&M	aSAV	pLIFE
DCLEH250	Dairy Covere	250	15,000	54,500	69,500	2,100	10,600	15
DCLEH500	Dairy Covere	500	15,000	84,800	99,800	4,200	21,300	15
DCLEH1000	Dairy Covere	1000	18,100	145,700	163,800	8,500	42,600	15
DCMEH250	Dairy Compl	250	24,000	93,400	117,400	1,500	8,600	20
DCMEH500	Dairy Compl	500	31,500	136,700	168,200	3,100	17,100	20
DCMEH1000	Dairy Compl	1000	48,400	213,400	261,800	6,100	34,300	20
DPFEH250	Dairy Plug Fl	250	18,800	79,000	97,800	1,100	6,200	15
DPFEH500	Dairy Plug Fl	500	24,700	105,400	130,100	2,200	12,500	15
DPFEH1000	Dairy Plug Fl	1000	35,500	154,800	190,300	4,400	24,900	15
SDPFE300	SD Dairy Plu	300	NA	144,047	144,047	3,269	15,122	15
SDPFA300	SD Dairy Plu	300	NA	144,047	144,047	3,269	27,720	15
TXCLA500	TX Dairy Co	500	NA	128,082	128,082	3,813	18,784	15
CACLE1000	CA Dairy Co	1000	NA	201,466	201,466	7,625	32,291	15
CACLA1000	CA Dairy Co	1000	NA	201,466	201,466	7,625	44,243	15

Swine Farms w/ On-Farm Electricity Generation & All Manure Collected (100%)

SYSTEM	NAME	HEAD	SITING	TKEY	sum	aO&M	aSAV	pLIFE
SCLEH500	Swine Cover	500	8,500	40,400	48,900	1,100	6,100	15
SCLEH1000	Swine Cover	1000	11,600	60,100	71,700	2,300	12,300	15
SCLEH5000	Swine Cover	5000	40,600	209,000	249,600	11,300	61,300	15
SCMEH500	Swine Compl	500	16,700	69,300	86,000	1,000	6,400	20
SCMEH1000	Swine Compl	1000	21,400	90,600	112,000	2,000	12,700	20
SCMEH5000	Swine Compl	5000	53,900	238,500	292,400	10,300	63,700	20
NBCME10k	NB Swine Co	10000	NA	249,753	249,753	9,447	36,575	20
NBCMA10k	NB Swine Co	10000	NA	249,753	249,753	9,447	42,465	20

complete mix. Each digester type was evaluated under two specific scenarios. The first scenario accounted for a full revenue stream, which includes savings from on-farm electricity and heat recovery offsets, surplus electricity sales, manure disposal savings, and the sale of digested solids. The second scenario evaluated each digester technology, accounting only for savings from on-farm electricity offsets and surplus electricity sales. All of the basic system data used for this second objective were drawn from a Western Regional Biomass Energy Program[2] (WRBEP) study, and are also listed in Table 3.1.1. Some WRBEP assumptions were modified during the modeling, as will also noted later.

To accomplish these two objectives, the basic system data and additional macro variables, to be detailed later, were linked into CashFlow©, a model that provides a summary of primary investment merit statistics. The investment merit statistics of interest are Net Present Value (NPV), Internal Rate of Return (IRR), Simple Payback Period (SPP), and Cumulative Cash Flow (CCF). All of the investment merit statistics are related, and for comparative purposes they will be benchmarked later.

Before proceeding, some preliminary economic concepts should be briefly discussed. The interrelationship of investment merit statistics is at the center of economic evaluation. The most readily understood statistic is cash flow. Cash flow is a schedule of annual net profit (or loss) resulting from an investment and can take into account such factors as amortization or the inflation rate for displaced fuels. The important point about cash flow is that "less money spent" is equal to "more money made". However, cash flow does not account for the time value of money. The time-value of money concept explains that a current dollar is more valuable than a future dollar. To assess true profitability, cash flows must be adjusted by the discount rate in order to put dollars into a consistent present value. The discount rate can be interpreted as the interest rate anticipated on an alternate investment opportunity, against which the prime opportunity is compared in order to evaluate the financial consequence of going with the prime. The interrelationship of these investment merit statistics is briefly discussed below.

Simple Payback Period (SPP) is often used as a criterion for determining investment acceptability. From cash flow, a SPP for the investment can be quickly calculated. SPP is the "break-even" length of time necessary to recover the initial investment through positive cash flow. Many businesses will only undertake investments with a two-year SPP. However, while payback may be useful in measuring the liquidity of an investment, it offers no real insight on profitability because the analysis is incomplete. Neither the time value of money, nor positive cash flow occurring after the payback period is accounted for. Hence, for mutually exclusive projects with equal cash flows, the project with an infinite lifetime would receive the same ranking as a project with a very short lifetime if they both had the same payback period.

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[2]. Whittier, *et. al* (1993) Energy Conversion of Animal Manures: Feasibility Analysis for Thirteen Western States. Western Regional Biomass Energy Program, Golden, CO.

Net Present Value (NPV) is an investment merit statistic that accounts for the time value of money by describing the present worth of an investment in dollars. It is calculated by the compound discounting of the investment's annual cash flow with a specified discount rate, and then totaling the discounted cash flows over the investment life to arrive at its net value. If NPV is a positive figure, the investment provides a greater return than the alternate choice assumed by the discount rate. If the NPV is a negative figure, the alternate presents the better opportunity. If NPV equals zero, it is said the choices are indifferent. When there is more than one competing investment, the higher NPV is preferred. However, in a capital rationing situation, NPV has an inherent bias in favor of large projects.

Internal Rate of Return (IRR) is related to NPV and is a percentage figure providing the discount rate yielding a zero NPV. IRR allows direct comparison between the yields offered by different investment opportunities. If the IRR from an investment is greater than the discount rate, the investment is more worthwhile than the alternate choice. However, IRR suffers in two areas. First, if a project has a cash outflow at its end, multiple rates of return exist. While this is not the case with the data herein analyzed, the situation occurs, for example, in circumstances where there are abandonment costs. Second, a bias is introduced in the implicit assumption that all positive cash flows are reinvested over the remaining project life at the calculated IRR. "This may be an unrealistic assumption, especially for projects with relatively high Internal Rates of Return. While this does not affect the decision to accept or reject a project, it does affect the relative ranking of projects when comparing their relative profitability."[3]

Although the IRR and NPV methods will lead to the same decision whether to accept or reject an individual project, they can provide conflicting clues when the decision is a choice between mutually exclusive projects. That is, one project can have a higher IRR but lower NPV. This problem arises because the IRR is the implied reinvestment rate in the IRR method, while the discount rate is the implicit reinvestment rate used in the NPV method. NPV is generally superior because reinvestment will likely occur at a rate close to the cost of capital.

After estimating the investment merit statistics with CashFlow©, an additional step was required to accomplish the first stated objective: estimate digester cost and IRR as functions of herd size. Two simple (two-variable) linear regression models were developed for each of the seven digester scenarios. From econometric theory, a simple regression model is used for testing hypotheses about the relationship between a dependent variable (y) and an explanatory variable (x) and for making predictions. The system capital cost information and IRR estimates provided by CashFlow© for each herd size were aggregated for each of the seven digester scenarios. Simple regression analyses were then performed to evaluate the relationship between herd size and capital cost and herd size and IRR for each digester scenario.

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[3]. McGuigan, J. & Moyer, R. (1975) *Managerial Economics: Private and Public Sector Decision Analysis.* The Dryden Press, Hinsdale, IL.

The estimating equations were evaluated for goodness of fit and correlation. Theoretically, the closer the observations fall to the regression line, the greater the variation "explained" by the estimating equation. The coefficient of determination (R^2) is defined as the proportion of the total variation in the dependent variable (cost or IRR in this case) explained by the regression of those factors on herd size. A correlation coefficient (the square root of R^2) measures the degree of association between two variables (herd size and digester cost or IRR) and whether the variables move in the same (positive correlation) or in the opposite direction (negative correlation). Because it is generally assumed that there is a positive relationship between digester cost and IRR as a function of herd size, the models were developed with these expectations. Correlation between variables does not imply causality or dependence between them. After testing the significance of the parameter estimates using the *t* distribution, the regression analyses were then used for predicting the capital cost of installing an anaerobic digester and the minimum herd size required for a digester's profitable operation. Because of the small number of samples (three) for each digester scenario, this information should only be used with a high degree of caution.

As noted earlier, some macro variables, those general assumptions shared by all projects, were used in the CashFlow® analyses. These assumed macro variables are listed in Table 3.1.2 and include: real growth rate in operation and maintenance expenses, real growth rate in energy expenses, percent real discount rate, percent combined tax rate, and depreciation of system capital costs method. The values for real growth rate in operation and maintenance expenses and real growth rate in energy expenses were *a priori* choices. A zero real growth rate in energy prices was used in evaluating the treatment technologies to account for a hypothetical "worst-case". It was assumed that the labor and materials required for operation and maintenance rose at a positive real rate above energy prices. The real rate of growth in the employment cost index has averaged about the same as the general rate of inflation since 1990.

TABLE 3.1.2: MACRO VARIABLES USED IN CashFlow® MODEL

Real Growth Rate in O&M Expenses	1.5 Percent
Real Growth Rate in Energy Expenses	0.0 Percent
Real Discount Rate	8.5 Percent
Combined Marginal Tax Rate	40.0 Percent
Depreciation Method	7-Year 150 Percent Declining Balance Modified Accelerated Recovery System

Although all of the system data for the analyses were taken directly from the USEPA and WRBEP studies without question as to their veracity, a number of different key assumptions were used with the data herein.

The first area of difference relates to project life. Both USEPA and WRBEP estimated that the project life of all anaerobic digestion technologies is 10 years. As will be shown in Section 4, there are a number of operating on-farm digesters that have demonstrated practical lives longer than a 10 year period. Based on this objective evidence, it was assumed that well designed and maintained covered lagoon and plug flow digesters have a project life of no less than 15 years. Because the tank of a complete mix digester is likely to be either metal or concrete, the project life of this technology was assumed to be no less than 20 years. In the real world, the actual project lifetime may exceed these values for well designed and maintained digesters.

The second area of difference relates to discount rate. Without belaboring the point, the choice of a discount rate is essential to the outcome: what may appear to be justified with a low discount rate may be imprudent at a higher rate. There are a number of problems with estimating a discount rate for farm-based technologies. Basic questions arise; for example, what is a true discount rate for livestock producers? What level of risk, and hence discount rate, does the investment in anaerobic digestion technology really represent? The range could lie between the yield of the "risk-free" investments made by the Treasury Department to that of a more speculative "junk" bond. Finally, private sector externalities are not accounted for within the discount rate. Mitigation of environmental externalities can be a major factor leading to investment in anaerobic digestion technology.

WRBEP estimated the nominal discount rate to be 9 percent, with an estimated inflation rate of 5 percent. USEPA settled on a nominal discount rate of 12 percent, using the "rule of thumb" that businesses establish a hurdle rate for new initiatives at the prime rate of interest plus 6 percent. Moreover, WRBEP and USEPA estimates were in nominal rates, which include current and expected inflation rates, instead of the real discount rate economists desire, that is, one which factors out inflation. Since it is beyond the scope of this paper to further delineate the "true" discount rate for livestock producers, an appropriate discount rate here was assumed *per* USEPA (prime rate of interest plus 6 percent). This helps to simplify the issue of how to incorporate investment risk. It was also assumed the analyses presented here there was a constant inflation rate equal to 3.5 percent annually, which is about the same as the three-year average percentage change in the implicit price deflator reported for purchases of goods and services. The average prime rate of interest for the past twelve months has been 6.0 percent. Because the inflation rate was small, by subtraction, the real discount rate implied is approximately 8.5 percent (6 percent + 6 percent - 3.5 percent = 8.5 percent).

Another significant difference in the assumptions used is in the area of depreciation of capital equipment. Following the expiration of the business and energy tax credits with the passage of the federal Tax Reform Act of 1986, depreciation of capital equipment is one of few incentives which can legitimately increase economic performance of anaerobic digestion technologies. Both USEPA and WRBEP used a 10 year straight line depreciation method. After review of Internal Revenue Service publications[4], a seven-year 150% Declining Balance General Depreciation System (150% DB-GDS) election offered under the Modified Accelerated Cost Recovery System (MARCS) was chosen for the analyses presented here. The depreciation method and time period is one election under the MARCS. Although it appears that the 200% Double DB-GDS can also be used in situations involving ownership by an unrelated party, the 150% DB-DGS is directed toward farm rather than nonfarm property classes. As with all matters related to taxes, a competent accountant or attorney should be consulted to maximize all legitimate incentives that exist for specific situations.

There were a number of other smaller-impact changes in the driving assumptions. USEPA assumed a zero salvage value at the end of project life, and WRBEP assumed a salvage value of 10 percent for a complete mix digesters and 20 percent for plug flow or covered lagoon digesters. This study assumed a zero salvage value *per* USEPA. USEPA assumed a combined tax rate of 40 percent, and WRBEP assumed a combined tax rate of 20 percent. To be conservative in estimating tax rates, this study assumed a 40 percent combined tax rate *per* USEPA. Additionally, all financial exchanges were assumed to be "cash-and-carry" with no budget constraints. USEPA assumed the same. WRBEP assumed that the investment would be financed with an interest rate of 9.25 percent following a down payment of 1/3 of the total project costs. The last difference in assumptions is in the use of the end-of-year convention. Herein, it was assumed that all of the project capital costs were incurred during Time 0. The issue may be esoteric, but it is related to estimating NPV and IRR, because project capital costs accounted for in years following Time 0 are discounted.

3.2 DAIRY FARM DIGESTERS WITH LOW MANURE COLLECTED

This section evaluates the investment merit of two types of anaerobic digesters used on dairy farms with herd sizes of 250, 500 and 1000 cows. Herd size refers to the number of milking cows having the average weight of 1,400 pounds. Dairy farms used two manure collection scenarios, apron only collection and apron and parlor collection. The scenario evaluated in this section was apron only, which resulted in a low manure collection of 15 percent of the total manure volume generated on the farm. For the purpose of estimating biogas recovery rates, the covered lagoon digester was assumed to be located in Erath County, Texas. The digester capital costing information represented the total "turn-key" cost of all materials, labor and engineering services required to bring a project on-line. The value of the digester was

[4]. IRS Publication 534: Depreciation and IRS Publication 946: How to Begin Depreciating Your Property.

a function of how the energy was used, in other words, the direct energy costs avoided by the farmer. No credit was assumed for reducing environmental externalities. The assumed value of each digester was established by the amount of electricity generated and heat reclaimed from the engine/generator. The electricity was used on-farm as an offset for currently-purchased power utilized for milk chillers, fan and pump motors, and other equipment. On-farm water heating and milk cooling requirements can also be met with commercially available biogas-fired heaters and chillers. In determining the avoided cost of purchased power, the electricity rate used was a representative national average of $0.065 per kWh. Annual operating and maintenance costs were used as provided.

3.2.1 250-HEAD DAIRY FARM WITH ELECTRICITY GENERATION

Table 3.2.1 provides the investment merit statistics for a herd of 250 dairy cows. As mentioned earlier, a positive NPV indicates that a project is cost-effective. The NPV data indicates that neither the covered lagoon nor the complete mix digester was cost-effective, given the assumptions used. Graphic evaluation of the other investment merit statistics for the two treatment techniques provides a SPP of slightly over 13 years for the covered lagoon digester _v._ more than 20 years for the complete mix digester (Figure 3.2.1). There were two sensitivity analyses performed on the two treatment choices. The first determines NPV to real discount rate, which will find if there is a positive discount rate yielding a positive NPV. Figure 3.2.2 reveals that the real discount rate must be less than 2.5 percent if the covered lagoon digester is to be cost-effective. No positive-valued real discount rate that would indicate investment merit was found for the complete mix digester. The second sensitivity analysis determined IRR to project life. This sensitivity reveals the time period required to recover investment and is indicated by crossing the established hurdle rate in "discounted" dollars; it can be thought of as providing a project's discounted (true) payback period (DPP). As shown in Figure 3.2.3, because the NPV for both digesters is negative, neither cross the established hurdle rate during its project lifetime.

TABLE 3.2.1: 250-HEAD DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION

DEL250	Covered Lagoon	Complete Mix
NPV ($)	(16,545)	(43,782)
IRR (%)	1.2	(4.9)
SPP (years)	13.3	> 20.0
CCF ($)	3,834	(23,850)

3.2.2 500-HEAD DAIRY FARM WITH ELECTRICITY GENERATION

Table 3.2.2 provides the investment merit statistics for a herd of 500 dairy cows. As mentioned earlier, a positive NPV indicates that a project is cost-effective. The NPV data in Table 3.2.2, once again, reveals that neither the covered lagoon nor the complete mix digesters has investment merit, given the assumptions used. In Figure 3.2.4, a graphic evaluation of the other investment merit statistics for the two treatment techniques provides a SPP of about 8.5 years for the covered lagoon digester v. more than 20 years for the complete mix digester. With respect to the two sensitivity analyses conducted, NPV to real discount rate (Figure 3.2.5) reveals that the real discount rate must be less than 6.5 percent for the covered lagoon digester to be cost-effective. No positive-valued real discount rate that would provide investment merit was found for the complete mix digester. The second sensitivity analysis of IRR to project life (Figure 3.2.6) demonstrates that the period required to recover investment costs as indicated by crossing the established hurdle rate does not occur during the project lifetimes.

TABLE 3.2.2: 500-HEAD DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION

DEL500	Covered Lagoon	Complete Mix
NPV ($)	(7,744)	(44,325)
IRR (%)	6.0	(1.5)
SPP (years)	8.5	> 20.0
CCF ($)	28,609	(10,439)

3.2.3 1000-HEAD DAIRY FARM WITH ELECTRICITY GENERATION

Table 3.2.3 provides the investment merit statistics for a herd of 1000 dairy cows. The positive NPV found for the covered lagoon digester indicates that the project has investment merit, and project implementation would add over $80,000 in net farm income during its life. Evaluation of the NPV data in Table 3.2.3 illustrates that the complete mix digester is still not cost-effective, given the assumptions used. Graphic evaluation of the other investment merit statistics for the two treatment techniques provides a SPP of a little more than 6 years for the covered lagoon digester v. more than 18 years for the complete mix digester (Figure 3.2.7). With respect to the NPV to real discount rate sensitivity analyses conducted, Figure 3.2.8 demonstrates that in order for the covered lagoon digester *not* to be cost-effective, the real discount rate must be more than 10.5 percent. A real discount rate of less than 1.5 percent would provide investment merit for the complete mix digester. The second sensitivity analysis, IRR to project life (Figure 3.2.9), reveals that an 11 year time period is required to recover investment costs for the covered lagoon digester. Since the complete mix digester does not have a positive NPV, it does not cross the established hurdle rate during its project life.

TABLE 3.2.3: 1000-HEAD DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION

DEL1000	Covered Lagoon	Complete Mix
NPV ($)	11,253	(44,620)
IRR (%)	10.8	1.5
SPP (years)	6.4	16.5
CCF ($)	80,359	14,754

3.2.4 REGRESSION ANALYSES OF DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION AND LOW MANURE COLLECTED

After calculating the investment merit statistics, an additional step was required to accomplish the first stated objective: estimate digester cost and IRR as functions of herd size. This section presents the results of two simple linear regression models that accomplish this objective.

As shown in Table 3.2.4, the cost function for a covered lagoon digester indicates that all points lie on the function's regression line. The cost function correlation coefficient suggests a perfect positive linear correlation between herd size and the cost of constructing a digester. Both the constant and coefficient "t" statistics for the cost function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, they are both statistically significant at that level. The regression equation that was estimated for the cost function is graphically presented in Figure 3.2.10.

The IRR function for a covered lagoon digester indicates that the regression equation explains about 96 percent of the total variation in IRR. The remaining 4 percent is attributed to error term factors. The IRR function correlation coefficient is a near perfect positive linear correlation. However, neither the constant nor coefficient "t" statistics for the IRR function exceeds the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, the variables are not statistically significant at that level. It is possible that a different functional form, such as a double log, would provide a better fit than the linear form. The regression equation that was estimated for the IRR function is graphically presented in Figure 3.2.11 and has a confidence level of one negative standard error incorporated. The IRR function was algebraically manipulated to provide the minimum herd size needed to operate a covered lagoon digester on a dairy farm with electricity generation and low manure collection. This was estimated to be between 784 and 890 cows at the established real discount rate of 8.5 percent.

TABLE 3.2.4: DAIRY FARM COVERED LAGOON DIGESTER WITH ELECTRICITY GENERATION AND LOW MANURE COLLECTED

DCLEL	Cost Function	IRR Function
R^2	1.00	0.96
r	1.00	0.98
Constant "t"	223.94	-0.76
Coefficient "t"	210.50	5.05
Estimating Equation	y = 36,650 + 52(x)	y = -1.23 + 0.012(x)
Minimum Herd Size	N/A	784 to 890

As shown in Table 3.2.5, the cost function for a complete mix digester indicates that all points lie on the function's regression line. The cost function correlation coefficient suggests a perfect positive linear correlation between herd size and the cost of constructing a digester. Since both the constant and coefficient "t" statistics for the cost function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, they are both statistically significant at that level. The regression equation that was estimated for the cost function is graphically presented in Figure 3.2.12.

The IRR function for a complete mix digester indicates that the regression equation explains about 95 percent of the total variation in IRR. The remaining 5 percent is attributed to error term factors. The IRR function correlation coefficient is a near perfect positive linear correlation. However, like the covered lagoon digester earlier, neither the constant nor coefficient "t" statistics for the IRR function exceeds the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance. This leads to the conclusion that the variables are not statistically significant at that level. It is possible that a different functional form, such as a double log, would provide a better fit than the linear form. The regression equation that was estimated for the IRR function is graphically presented in Figure 3.2.13 and has a confidence level of one negative standard error incorporated. The IRR function was algebraically manipulated to provide the minimum herd size needed to operate a complete mix digester on a dairy farm with electricity generation and low manure collection. This was estimated to be between 1,838 and 1,962 cows at the established real discount rate of 8.5 percent.

TABLE 3.2.5: DAIRY FARM COMPLETE MIX DIGESTER WITH ELECTRICITY GENERATION AND LOW MANURE COLLECTED

DCMEL	Cost Function	IRR Function
R^2	1.00	0.95
r	1.00	0.97
Constant "t"	52.53	-5.16
Coefficient "t"	33.94	4.34
Estimating Equation	y = 61,900 + 60(x)	y = -6.37 + 0.008(x)
Minimum Herd Size	N/A	1,838 to 1,962

3.3 DAIRY FARM DIGESTERS WITH HIGH MANURE COLLECTED

This section evaluates the investment merit of three types of anaerobic digesters used on dairy farms with herd sizes of 250, 500 and 1000 cows. Herd size refers to the number of milking cows having the average weight of 1,400 pounds. Dairy farms used two manure collection scenarios, apron only collection and apron and parlor collection. The scenario evaluated in this section is apron and parlor, which results in high manure collection of 55 percent of the total manure volume generated on the farm. For the purpose of estimating biogas recovery rates, the covered lagoon digester was assumed to be located in Erath County, Texas. In addition to a covered lagoon and a complete mix digester, a plug flow digester was also analyzed. For the plug flow digester, however, the solids content of the manure washed from the milking parlor was assumed to be too low for use, consequently, only 40 percent of the manure found on the feed apron would likely be managed with this recovery option. This assumption may not be true in the practical application of plug flow digesters. The digester capital costing information represented the total "turn-key" cost of all materials, labor and engineering services required to bring a project on-line. The value of the digester was a function of how the energy was used, in other words, the direct energy costs avoided by the farmer. No credit was assumed for reducing environmental externalities. The assumed value of each digester was established by the amount of electricity generated and heat reclaimed from the engine/generator. The electricity was used on-farm as an offset for currently-purchased power utilized for milk chillers, fan and pump motors, and other equipment. On-farm water heating and milk cooling requirements can also be met with commercially available biogas-fired heaters and chillers. In determining the avoided cost of purchased power, the electricity rate used was a representative national average of $0.065 per kWh. Annual operating and maintenance costs were used as provided.

3.3.1 250-HEAD DAIRY FARM WITH ELECTRICITY GENERATION

Table 3.3.1 provides the investment merit statistics for a herd of 250 dairy cows. As mentioned earlier, a positive NPV indicates that a project is cost-effective. The NPV data in Table 3.3.1 reveals that none of the digesters has investment merit given the assumptions used. In Figure 3.3.1, a graphic evaluation of the other investment merit statistics for the three treatment techniques provides a SPP of slightly over 8 years for the covered lagoon digester v. 17 years for the complete mix digester v. more than 20 years for the plug flow digester. As earlier, there were two sensitivity analyses conducted. The first, NPV to real discount rate, finds if there is a positive discount rate yielding a positive NPV. Figure 3.3.2 reveals that in order to have investment merit, the real discount rate must be less than 6.5 percent for the covered lagoon digester and less than 1.5 percent for the complete mix digester. No positive-valued real discount rate was found for the plug flow digester which provided investment merit. The second sensitivity analysis, IRR to project life, provided a project's discounted (and therefore true) payback period (DPP). As shown in Figure 3.3.3, because the NPV for the three digesters is negative, none crosses the established hurdle rate during its project lifetime.

TABLE 3.3.1: 250-HEAD DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION

DEH250	Covered Lagoon	Complete Mix	Plug Flow
NPV ($)	(7,912)	(43,995)	(44,510)
IRR (%)	6.2	1.2	(2.4)
SPP (years)	8.3	17.0	> 20.0
CCF ($)	32,681	11,949	(13,890)

3.3.2 500-HEAD DAIRY FARM WITH ELECTRICITY GENERATION

Table 3.3.2 provides the investment merit statistics for a herd of 500 dairy cows. As mentioned earlier, a positive NPV indicates that a project is cost-effective. The positive NPV data found for the covered lagoon digester indicates that the project has investment merit, and that project implementation would add close to $90,000 in net farm income during its life. Evaluation of the NPV data in Table 3.3.2 reveals that neither the complete mix nor the plug flow digester has investment merit, given the assumptions used. Graphical evaluation of the other investment merit statistics for the three treatment techniques in Figure 3.3.4 provides a SPP of about 6.5 years for the covered lagoon digester v. more than 12 years for both the complete mix and plug flow digesters. With respect to the NPV to real discount rate sensitivity analysis, Figure 3.3.5 demonstrates that in order for the covered lagoon digester *not* be cost-effective, the real discount rate must be more than 10.5 percent. A real discount rate of 4.0 percent for the complete mix digester and 1.5 percent for the plug flow digester would indicate investment merit. The second sensitivity analysis, IRR to project life (Figure 3.3.6), demonstrates that the covered lagoon digester requires an 11 year period to cross the established hurdle rate and recover investment costs. The time required to cross the established hurdle rate and recover investment costs for the complete mix and plug flow digesters is not within their project lifetimes.

TABLE 3.3.2: 500-HEAD DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION

DEH500	Covered Lagoon	Complete Mix	Plug Flow
NPV ($)	12,507	(41,902)	(42,014)
IRR (%)	10.8	4.0	(1.4)
SPP (years)	6.4	12.3	12.9
CCF ($)	89,781	61,270	12,420

3.3.3 1000-HEAD DAIRY FARM WITH ELECTRICITY GENERATION

Table 3.3.3 provides the investment merit statistics for a herd of 1000 dairy cows. As mentioned earlier, a positive NPV indicates that a project is cost-effective. The positive NPV data found for the covered lagoon digester indicates that the project has investment merit, and that project implementation would add over $200,000 in net farm income during its life. Evaluation of the NPV data in Table 3.3.3 reveals that neither the complete mix nor the plug flow digester has investment merit, given the assumptions used. Graphical evaluation of the other investment merit statistics for the three treatment techniques in Figure 3.3.7 provides a SPP of a little more than 5.5 years for the covered lagoon digester v. more than 9 years for both the complete mix and plug flow digesters. With respect to the NPV to real discount rate sensitivity analysis, Figure 3.3.8 demonstrates that in order for the covered lagoon digester *not* to be cost-effective, the real discount rate must be more than 14 percent. A real discount rate of less than 6.5 percent provides investment merit for the complete mix digester. A real discount rate of less than 5 percent is required to provide investment merit for the plug flow digester. The sensitivity analysis of IRR to project life (Figure

3.3.9), demonstrates that the covered lagoon digester requires an 8 year period to cross the established hurdle rate and recover investment costs. Since neither the complete mix nor plug flow digester has a positive NPV, they do not cross the established hurdle rate during their project lifetimes.

TABLE 3.3.3: 1000-HEAD DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION

DEH1000	Covered Lagoon	Complete Mix	Plug Flow
NPV ($)	49,891	(29,638)	(34,897)
IRR (%)	13.9	6.6	4.7
SPP (years)	5.6	9.4	9.4
CCF ($)	200,041	169,887	65,879

3.3.4 REGRESSION ANALYSES OF DAIRY FARM DIGESTERS WITH ELECTRICITY GENERATION AND HIGH MANURE COLLECTED

After calculating the investment merit statistics, an additional step was required to accomplish the first stated objective: estimate digester cost and IRR as functions of herd size. This section presents the results of the two simple linear regression models that accomplish this objective.

As shown in Table 3.3.4, the cost function for a covered lagoon digester indicates that all points lie on the function's regression line. The cost function correlation coefficient suggests a perfect positive linear correlation between herd size and the cost of constructing a digester. Both the constant and coefficient "t" statistics for the cost function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance. This leads to the conclusion that they are both statistically significant at that level. The regression equation that was estimated for the cost function is graphically presented in Figure 3.3.10.

The IRR function for a covered lagoon digesters indicates that the regression equation explains about 91 percent of the total variation in IRR. The remaining 9 percent is attributed to error term factors. The IRR function correlation coefficient is a near perfect positive linear correlation. However, neither the constant nor coefficient "t" statistics for the IRR function exceeds the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, the variables are not statistically significant at that level. It is possible that a different functional form, such as a double log, would provide a better fit than the linear form. The regression equation that was estimated for the IRR function is graphically presented in Figure

3.3.11 and has a confidence level of one negative standard error incorporated. The IRR function was algebraically manipulated to provide the minimum herd size needed to operate a covered lagoon digester on a dairy farm with electricity generation and high manure collection. This was estimated to be between 395 and 564 cows at the established real discount rate of 8.5 percent.

TABLE 3.3.4: DAIRY FARM COVERED LAGOON DIGESTER WITH ELECTRICITY GENERATION AND HIGH MANURE COLLECTED

DCLEH	Cost Function	IRR Function
R^2	1.00	0.91
r	1.00	0.95
Constant "t"	33.70	2.36
Coefficient "t"	74.92	3.20
Estimating Equation	y = 37,500 + 126(x)	y = 4.07 + 0.010(x)
Minimum Herd Size	N/A	395 to 564

As shown in Table 3.3.5, the cost function for a complete mix digester indicates that all points lie on the function's regression line. The cost function correlation coefficient suggests a perfect positive linear correlation between herd size and the cost of constructing a digester. Since both the constant and coefficient "t" statistics for the cost function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance, they are both statistically significant at that level. The regression equation that was estimated for the cost function is graphically presented in Figure 3.3.12.

The IRR function for a complete mix digester indicates that the regression equation explains about 96 percent of the total variation in IRR. The remaining 4 percent is attributed to error term factors. The IRR function correlation coefficient is a near perfect positive linear correlation. However, like the covered lagoon digester earlier, neither the constant nor coefficient "t" statistics for the IRR function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, the variables are not statistically significant at that level. It is possible that a different functional form would provide a better fit than the linear form. The regression equation that was estimated for the IRR function is graphically presented in Figure 3.3.13 and has a confidence level of one negative standard error incorporated. The IRR function was algebraically manipulated to provide the minimum herd size needed to operate a complete mix digester on a dairy farm with electricity generation and high manure collection. This was estimated to be between 1,251 and 1,367 cows at the established real discount rate of 8.5 percent.

TABLE 3.3.5: DAIRY FARM COMPLETE MIX DIGESTER WITH ELECTRICITY GENERATION AND HIGH MANURE COLLECTION

DCMEH	Cost Function	IRR Function
R^2	1.00	0.96
r	1.00	0.98
Constant "t"	26.96	-0.06
Coefficient "t"	48.44	4.66
Estimating Equation	y = 70,600 + 192(x)	y = -0.05 + 0.007(x)
Minimum Herd Size	N/A	1,251 to 1,367

As shown in Table 3.3.6, the cost function for a plug flow digester indicates that all points lie on the function's regression line. The cost function correlation coefficient suggests a perfect positive linear correlation between herd size and the cost of constructing a digester. Since both the constant and coefficient "t" statistics for the cost function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance, they are both statistically significant at that level. The regression equation that was estimated for the cost function is graphically presented in Figure 3.3.14.

The IRR function for a plug flow digester indicates that the regression equation explains about 95 percent of the total variation in IRR. The remaining 5 percent is attributed to error term factors. The IRR function correlation coefficient is a near perfect positive linear correlation. However, like the covered lagoon and complete mix digesters earlier, neither the constant nor coefficient "t" statistics for the IRR function exceeds the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, the variables are not statistically significant at that level. It is possible that a different functional form, such as a double log, would provide a better fit than the linear form. The regression equation that was estimated for the IRR function is graphically presented in Figure 3.3.15 and has a confidence level of one negative standard error incorporated. The IRR function was algebraically manipulated to provide the minimum herd size needed to operate a plug flow digester on a dairy farm with electricity generation and high manure collection. This was estimated to be between 1,378 and 1,505 cows at the established real discount rate of 8.5 percent.

TABLE 3.3.6: DAIRY FARM PLUG FLOW DIGESTER WITH ELECTRICITY GENERATION AND HIGH MANURE COLLECTED

DPFEH	Cost Function	IRR Function
R^2	1.00	0.95
r	1.00	0.97
Constant "t"	47.01	-2.87
Coefficient "t"	56.45	4.27
Estimating Equation	y = 67,700 + 123(x)	y = -4.04 + 0.009(x)
Minimum Herd Size	N/A	1,378 to 1,505

3.4 SWINE FARM DIGESTERS WITH ALL MANURE COLLECTED

This section evaluates the investment merit of two types of anaerobic digesters used on swine farms with herd sizes of 500, 1000 and 5000 hogs. Herd size refers to the number of on-farm animals having the average weight of 138 pounds per hog. It was assumed that all manure generated on the farm was collected. For the purpose of estimating biogas recovery rates, the covered lagoon digester was assumed to be located in Sampson County, North Carolina. The digester capital costing information represented the total "turn-key" cost of all materials, labor and engineering services required to bring a project on-line. The value of the digester was a function of how the energy was used, in other words, the direct energy costs avoided by the farmer. No credit was assumed for reducing environmental externalities. The assumed value of each digester was established by the amount of electricity generated and heat reclaimed from the engine/generator. The electricity was used on-farm as an offset for currently-purchased power utilized for fan and pump motors, and other equipment. In determining the avoided cost of purchased power, the electricity rate used was a representative national average of $0.065 per kWh. Annual operating and maintenance costs were used as provided.

3.4.1 500-HEAD SWINE FARM WITH ELECTRICITY GENERATION

Table 3.4.1 provides the investment merit statistics for a herd of 500 swine. As mentioned earlier, a positive NPV indicates that a project is cost-effective. The NPV data indicates that neither the covered lagoon nor the complete mix digester has investment merit, given the assumptions used. Graphic evaluation of the other investment merit statistics for the two treatment techniques provides a SPP of about 10 years for the covered lagoon digester *v.* more than 16 years for the complete mix digester (Figure 3.4.1). There were two sensitivity analyses performed on the two treatment choices. The first determines NPV to real discount rate, which will find if there is a positive discount rate yielding a positive NPV. Figure 3.4.2 indicates that the real discount rate must be less than 4.5 percent in order for the covered lagoon digester to have investment merit and less than 2 percent for the complete mix digester. The second sensitivity analysis determined IRR to project life. This figure reveals the time period required to recover investment when crossing the established hurdle rate in "discounted" dollars, and can be thought of as providing a project's discounted (and therefore true) payback period (DPP). As shown in Figure 3.4.3, because the NPV for both digesters is negative, neither crosses the established hurdle rate during its project lifetime.

TABLE 3.4.1: 500-HEAD SWINE FARM DIGESTERS WITH ELECTRICITY GENERATION

SEA500	Covered Lagoon	Complete Mix
NPV ($)	(10,288)	(31,036)
IRR (%)	4.1	1.6
SPP (years)	9.9	16.3
CCF ($)	14,550	11,326

3.4.2 1000-HEAD SWINE FARM WITH ELECTRICITY GENERATION

Table 3.4.2 provides the investment merit statistics for a herd of 1000 swine. As mentioned earlier, a positive NPV indicates that a project is cost-effective. The NPV data indicates that neither the covered lagoon nor the complete mix digester has investment merit, given the assumptions used. Graphic evaluation of the other investment merit statistics for the two treatment techniques provides a SPP of about 7.5 years for the covered lagoon digester *v.* about 10.5 years for the complete mix digester (Figure 3.4.4). The first sensitivity analysis performed, NPV to real discount rate (Figure 3.4.5) reveals that the real discount rate must be less than 8 percent in order for the covered lagoon digester to have investment merit and less than 5.5 percent for the complete mix digester. The second sensitivity analysis, IRR to project life (Figure 3.4.6), demonstrates that because the NPV for both digesters is negative, neither crosses the established hurdle rate during its project lifetime.

TABLE 3.4.2: 1000-HEAD SWINE FARM DIGESTERS WITH ELECTRICITY GENERATION

SEA1000	Covered Lagoon	Complete Mix
NPV ($)	(2,088)	(20,038)
IRR (%)	7.9	5.4
SPP (years)	7.4	10.6
CCF ($)	44,659	57,452

3.4.3 5000-HEAD SWINE FARM WITH ELECTRICITY GENERATION

Table 3.4.3 provides the investment merit statistics for a herd of 5000 swine. The positive NPV found for both the covered lagoon and complete mix digesters indicates that the two technologies have investment merit. Implementation of the covered lagoon project would add over $288,000 in net farm income during its life, and the complete mix project would add over $446,000 during its life. Graphic evaluation of the other investment merit statistics for the two treatment techniques provides a SPP of about 6 years for both digesters (Figure 3.4.7). With respect to the NPV to real discount rate sensitivity analysis, Figure 3.4.8 illustrates that in order for the two digesters *not* to have investment merit, the real discount rate must be more than 13.5 percent. The second sensitivity analysis, IRR to project life (Figure 3.4.9), reveals that about a 9 year time period is required to recover investment costs for the two treatment technologies.

TABLE 3.4.3: 5000-HEAD SWINE FARM DIGESTERS WITH ELECTRICITY GENERATION

SEA5000	Covered Lagoon	Complete Mix
NPV ($)	66,970	89,053
IRR (%)	13.3	13.1
SPP (years)	5.8	6.1
CCF ($)	288,835	446,056

3.4.4 REGRESSION ANALYSES OF SWINE FARM DIGESTERS WITH ELECTRICITY GENERATION AND ALL MANURE COLLECTED

After calculating the investment merit statistics earlier, an additional step was required to accomplish the first stated objective: estimate digester cost and IRR as functions of herd size. This section presents the results of the two simple linear regression models that accomplish this objective.

As shown in Table 3.4.4, the cost function for a covered lagoon digester indicates that all points lie on the function's regression line. The cost function correlation coefficient suggests a perfect positive linear correlation between herd size and the cost of constructing a digester. Both the constant and coefficient "t" statistics for the cost function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance. This leads to the conclusion that they are both statistically significant at that level. The regression equation that was estimated for the cost function is graphically presented in Figure 3.4.10.

The IRR function for a covered lagoon digester indicates that the regression equation explains about 90 percent of the total variation in IRR. The remaining 10 percent is attributed to error term factors. The IRR function correlation coefficient is a near perfect positive linear correlation. However, neither the constant nor coefficient "t" statistics for the IRR function exceeds the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, the variables are not statistically significant at that level. It is possible that a different functional form, such as a double log, would provide a better fit than the linear form. The regression equation that was estimated for the IRR function is graphically presented in Figure 3.4.11 and has a confidence level of one negative standard error incorporated. The IRR function was algebraically manipulated to provide the minimum herd size needed to operate a covered lagoon digester on a swine farm with electricity generation and all manure collected. This was estimated to be between 2,193 and 3,366 swine at the established real discount rate of 8.5 percent.

TABLE 3.4.4: SWINE FARM COVERED LAGOON DIGESTER WITH ELECTRICITY GENERATION AND ALL MANURE COLLECTED

SCLEA	Cost Function	IRR Function
R^2	1.00	0.90
r	1.00	0.95
Constant "t"	85.08	2.64
Coefficient "t"	417.27	2.97
Equation	y = 26,871 + 45(x)	y = 4.63 + 0.002(x)
Minimum Herd Size	N/A	2,193 to 3,366

As shown in Table 3.4.5, the cost function for a complete mix digester indicates that all points lie on the function's regression line. The cost function correlation coefficient suggests a perfect positive linear correlation between herd size and the cost of constructing a digester. Since both the constant and coefficient "t" statistics for the cost function exceed the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance, they are both statistically significant at that level. The regression equation that was estimated for the cost function is graphically presented in Figure 3.4.12.

The IRR function for a complete mix digester indicates that the regression equation explains about 95 percent of the total variation in IRR. The remaining 5 percent is attributed to error term factors. The IRR function correlation coefficient is a near perfect positive linear correlation. However, neither the constant nor coefficient "t" statistics for the IRR function exceeds the required *t* distribution number with 1 degree of freedom (df) at the 5 percent level of significance; therefore, the variables are not statistically significant at that level. It is possible that a different functional form, such as a double log, would provide a better fit than the linear form. The regression equation that was estimated for the IRR function is graphically presented in Figure 3.4.13 and has a confidence level of one negative standard error incorporated. The IRR function was algebraically manipulated to provide the minimum herd size needed to operate a complete mix digester on a swine farm with electricity generation and all manure collected. This was estimated to be between 2,948 and 3,757 swine at the established real discount rate of 8.5 percent.

TABLE 3.4.5: SWINE FARM COMPLETE MIX DIGESTER WITH ELECTRICITY GENERATION AND ALL MANURE COLLECTED

DCMEH	Cost Function	IRR Function
Model R^2	1.00	0.95
r	1.00	0.97
Constant "t"	33.41	1.04
Coefficient "t"	65.59	4.31
Equation	y = 64,726 + 46(x)	y = 1.65 + 0.002(x)
Minimum Herd Size	N/A	2,948 to 3,757

3.5 ILLUSTRATION OF CO-PRODUCT UTILIZATION

The second objective of this section is to illustrate the importance of maximizing co-product utilization and other offsets made available by adopting anaerobic digestion technology. As in the earlier evaluations, the types of digesters analyzed were covered lagoon, plug flow, and complete mix. Each digester type was evaluated under two specific scenarios. The first scenario accounted for a full revenue stream, which includes savings from on-farm electricity and heat recovery offsets, surplus electricity sales, manure disposal savings, and the sale of digested solids. The second scenario evaluated each digester technology accounting only for savings from on-farm electricity offsets and surplus electricity sales. As noted earlier, basic system data and additional macro variables were linked into CashFlow©, a model that provides a summary of primary investment merit statistics.

3.5.1 1000-HEAD CALIFORNIA DAIRY FARM WITH COVERED LAGOON DIGESTER

The manure was collected for this digester by a periodic scraping of the apron and feedlane and by the daily flushing of the milking parlor with water. It was assumed that the manure removed from the parlor and apron accounted for about 55 percent of the manure produced on the farm. The digested solids and liquids were assumed to have no monetary value, even though the liquids can be land applied with irrigation guns. The value of the 1000-head California covered lagoon digester was derived from the measure of offsets in currently purchased electricity and from the recovery of heat from the engine/generator which was used to warm dairy sanitary wash water. The digester was assumed to have an average production capacity of 81-kW, and annually produced 504,111 kWh. Purchased electricity costs had a demand charge of about $5.00 per kW, with an energy charge of $0.050 per kWh. Available waste heat was used as an offset for purchased propane costing $0.75 per gallon, with 2,800 Btu recovered for every kWh generated.

Table 3.5.1 provides the investment merit statistics for this project. As mentioned earlier, a positive NPV indicates that a project is cost-effective. Evaluation of the NPV data in Table 3.5.1 reveals that a covered lagoon digester has investment merit when both electricity and recovered heat can be used as creditable offsets in the analysis. But if, for example, the waste heat recovered from the engine/generator were to be used for heating the digester during the winter in cooler climates to balance daily biogas production, the covered lagoon digester no longer displays investment merit.

TABLE 3.5.1: 1000-HEAD CALIFORNIA DAIRY FARM WITH COVERED LAGOON DIGESTER

Statistic	Full Income	Electricity Only
NPV ($)	36,075	(23,476)
IRR (%)	11.8	6.2
SPP (years)	6.2	8.3
CCF ($)	200,987	93,419

3.5.2 300-HEAD SOUTH DAKOTA DAIRY FARM WITH PLUG FLOW DIGESTER

The manure was collected for this digester by a daily scraping of the apron and feedlane. It was assumed that 100 percent of the manure was collected and placed into the digester after it was diluted with a sufficient volume of water to produce the desired solids loading rate. The value of the 300-head South Dakota plug flow digester was derived, in part, from a change in manure management. It was assumed that the facility formerly used a hauling company to remove the manure from the farm at an annual cost of $2 per cow. This assumption means that the expenses associated with manure disposal were converted into revenue for the farm operator. It was also assumed that the digested solids were used as a soil amendment with a value of $2000 annually. The farm received offsets in currently purchased electricity and from the recovery of heat from the engine/generator which is used to warm dairy sanitary wash water. The digester was assumed to have an average production capacity of 35-kW, and annually produced 216,047 kWh. Purchased electricity costs had an energy-only charge of $0.075 per kWh. The digester produced more electricity than was consumed on the farm, and the surplus was sold at an avoided cost of $0.05 per kWh. Available waste heat was used as an offset for purchased propane costing $0.75 per gallon, with 2,800 Btu recovered for every kWh generated.

Table 3.5.2 provides the investment merit statistics for this example. As mentioned earlier, a positive NPV indicates that a project is cost-effective. Evaluation of the NPV data in Table 3.5.2 reveals that a plug flow digester has investment merit when all of the energy and recoverable co-products can be used as creditable offsets in the analysis. But if, for example, the manure disposal savings and digested solids recovered were not creditable, and the waste heat from the engine/generator was not recovered and was instead used to heat the digester during the winter, the plug flow digester no longer displays investment merit.

TABLE 3.5.2: 300-HEAD SOUTH DAKOTA DAIRY FARM WITH PLUG FLOW DIGESTER

Statistic	Full Income	Electricity Only
NPV ($)	18,124	(44,646)
IRR (%)	10.8	1.7
SPP (years)	6.4	12.5
CCF ($)	130,331	16,949

3.5.3 10,000-HEAD NEBRASKA SWINE FARM WITH COMPLETE MIX DIGESTER

It was assumed the complete mix digester was located on a farrow-to-finish farm using underfloor scrapers to move the manure from the production parlors to a holding pit. It was also assumed that 100 percent of the manure was collected and placed into the digester. The value of the 10,000-head Nebraska complete mix digester was derived from the measure of offsets that the farm received from currently purchased electricity and from recovery of heat from the engine/generator used for parlor heating. The digester had an average production capacity of 101-kW, and annually produced 624,137 kWh. Purchased electricity costs had an energy-only charge of $0.067 per kWh. The digester produced more electricity than was consumed on the farm, and the surplus was sold at an avoided cost of $0.04 per kWh. Available waste heat was used as an offset for purchased propane costing $0.75 per gallon, with 2,800 Btu recovered for every kWh generated.

Table 3.5.3 provides the investment merit statistics for this example. As mentioned earlier, a positive NPV indicates that a project is cost-effective. Evaluation of the NPV data in Table 3.5.3 reveals that a complete mix has investment merit when all of the energy and recoverable co-products can be used as creditable offsets in the analysis. But if, for example, the was heat recovered from the engine/generator were to be used for heating the digester during the winter in cooler climates, the complete mix digester is no longer cost-effective.

TABLE 3.5.3: 10,000-HEAD NEBRASKA SWINE FARM WITH COMPLETE MIX DIGESTER

Statistic	Full Income	Electricity Only
NPV ($)	4,146	(29,297)
IRR (%)	8.8	6.5
SPP (years)	7.8	9.4
CCF ($)	228,659	157,979

3.6 SUMMARY OF ECONOMIC EVALUATIONS

In this section, an economic guide was constructed to assess the benefit of anaerobic digesters. Three varieties of anaerobic digesters, covered lagoon, complete mix, and plug flow, were comparatively evaluated using three investment merit statistics: net present value, internal rate of return, and simple payback period. Life-cycle savings were estimated for the three types of digesters, with sensitivities considered for investment risk. A word of caution is in order. Some of the evaluations presented here should only be used as an rough estimator. The herd size cost-effective applications can be significantly lowered in areas that have higher energy rates than those assumed here.

Nevertheless, this section offers the following conclusions. First, a covered lagoon digester can have an economic advantage over both the complete mix and plug flow digesters because of lower capital cost and reduced operation and maintenance expenses. This advantage is reduced by the limited range of warm geographic locations where a covered lagoon digester can be cost-effectively used.

Second, a full range of creditable co-products that can be used as revenues in a *pro forma* analysis can make a significant difference in whether a project has investment merit for the user. Quite simply, it is very difficult to justify the investment in an anaerobic digester based only on the revenue received for offsetting currently purchased electricity and the sales of surplus electricity. The profitable operation is one that maximizes utilization of the digested liquids and solids as well.

Finally, economics is a science which is too often criticized for "knowing the price of everything and the value of nothing". The analyses presented here cannot give a quantifiable price impact for some of the subjective value advantages that can result from the adoption of anaerobic digestion technology.

For example, it is difficult to place a value on environmental externalities. Unrecovered methane in biogas produced by the inevitable decomposition of manures is a suspected agent of global climate change associated with the "greenhouse" effect. Conversion of biogas into less odious carbon dioxide can be accomplished through combustion by an engine/generator. A second unquantified externality is the ability of anaerobic digesters to help control odor and flies. With urban encroachment into rural areas, many farms today use a digester specifically installed for the purpose of odor control.

Other on-farm impacts are difficult to value. The installation of an anaerobic digester often reduces the direct labor requirements associated with daily manure management and the sometimes frequent need for holding pit pump-outs. Additional value can also be derived from reduction in the need to purchase fertilizers and soil conditioners. Just as many farmers do not charge for the value of their labor, many farmers also do not fully offset the cost reductions associated with using digested liquid nutrients or tilth-building solids.